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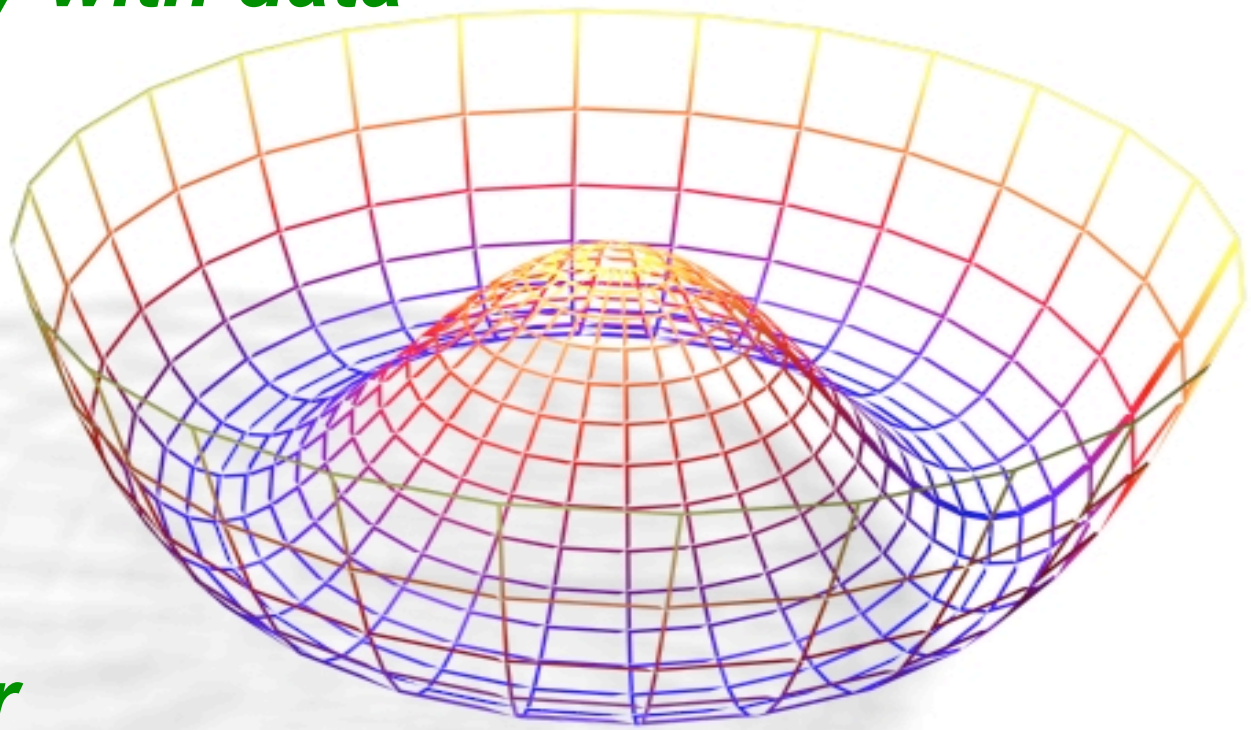
Unfolding EW & QCD Zjj:
A step towards measuring the Central Jet Veto efficiency with data



Kyle Cranmer
(BNL)

The Central Jet Veto

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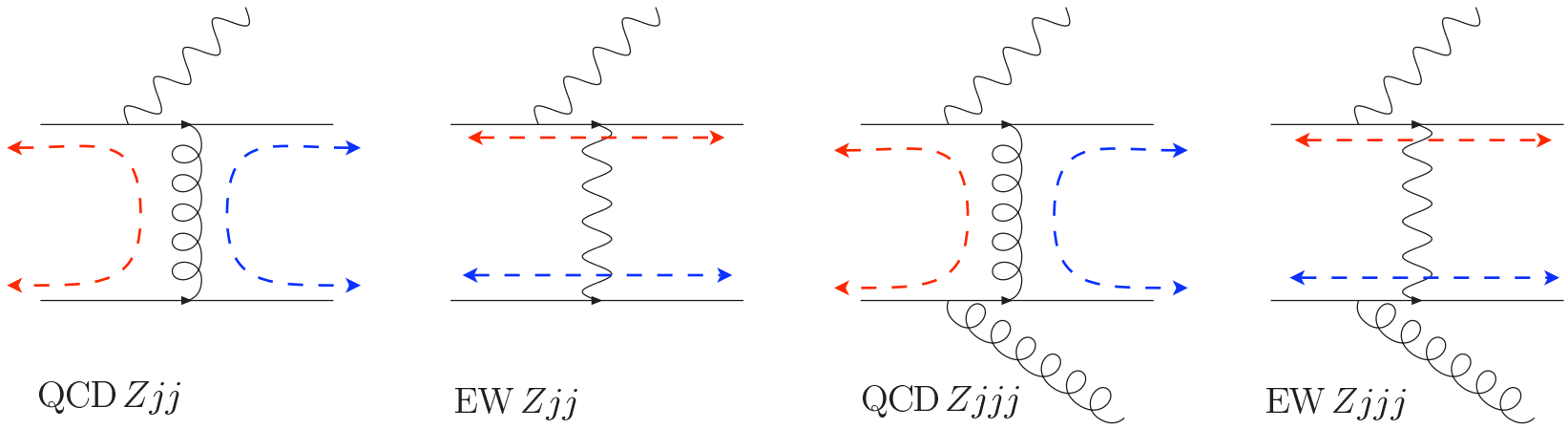
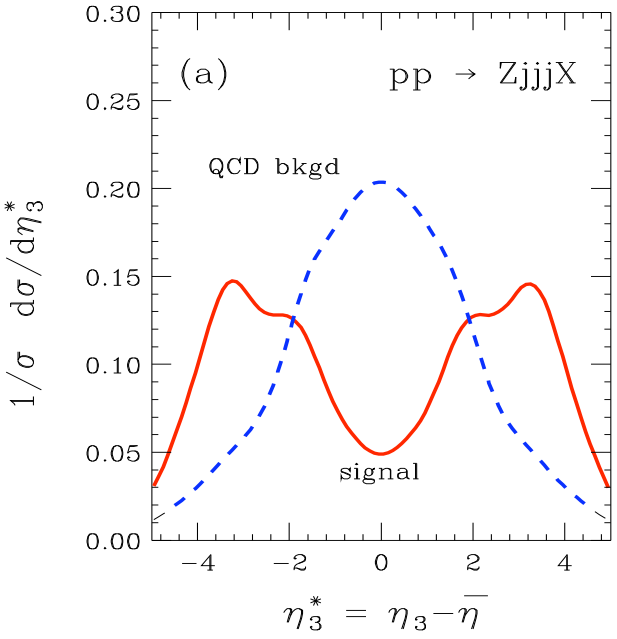
The dominant background for $H \rightarrow \tau\tau$ is the irreducible Z+jets





Flow of color-charge leads to different distributions for additional QCD radiation for Electroweak and QCD Zjj background

A Central Jet Veto is a major tool for the analysis

Precise knowledge of signal efficiency is crucial for limits and coupling measurements

Assumed Uncertanties

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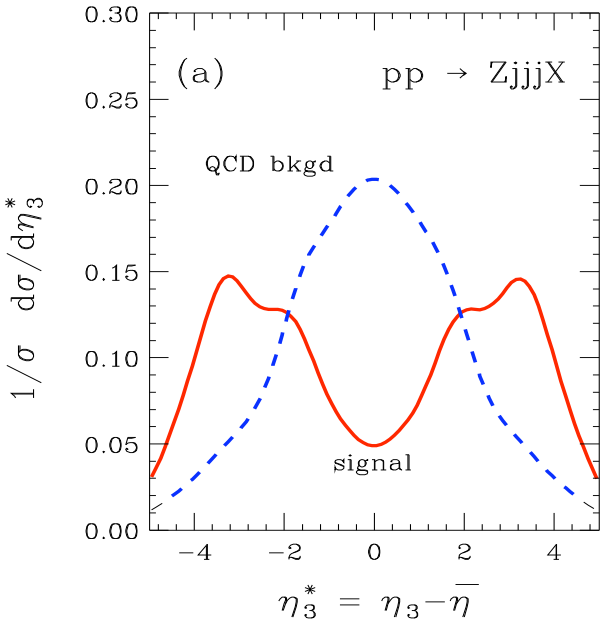
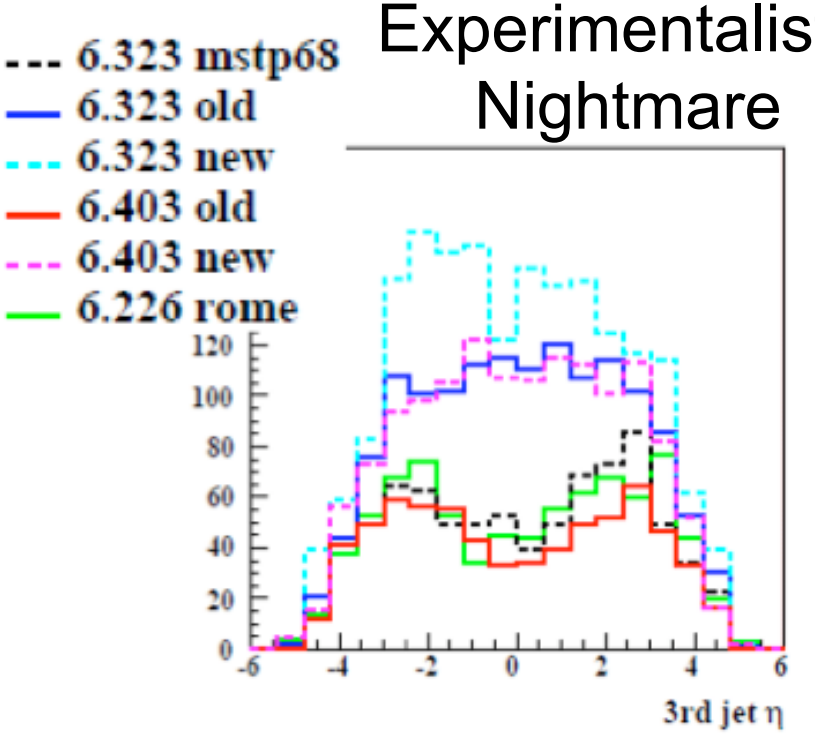
Assumed systematic uncertainties in the coupling measurements

L	5%	Measurement of luminosity
ϵ_D	2%	Detector efficiency
ϵ_L	2%	Lepton reconstruction efficiency
ϵ_γ	2%	Photon reconstruction efficiency
ϵ_b	3%	b-tagging efficiency
ϵ_τ	3%	hadronic τ-tagging efficiency
ϵ_{Tag}	5%	WBF tag-jets / jet-veto efficiency
ϵ_{Iso}	3%	Lepton isolation ($H \to ZZ \to 4\ell$)

Theorist's Dream



Experimentalist's Nightmare



Assumed Uncertanties

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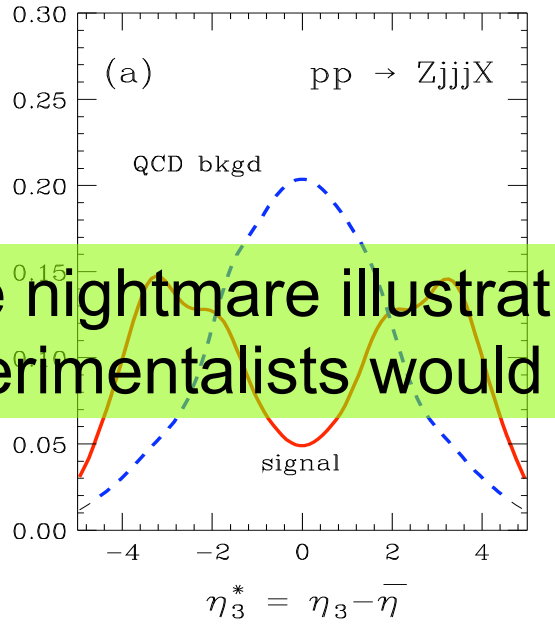
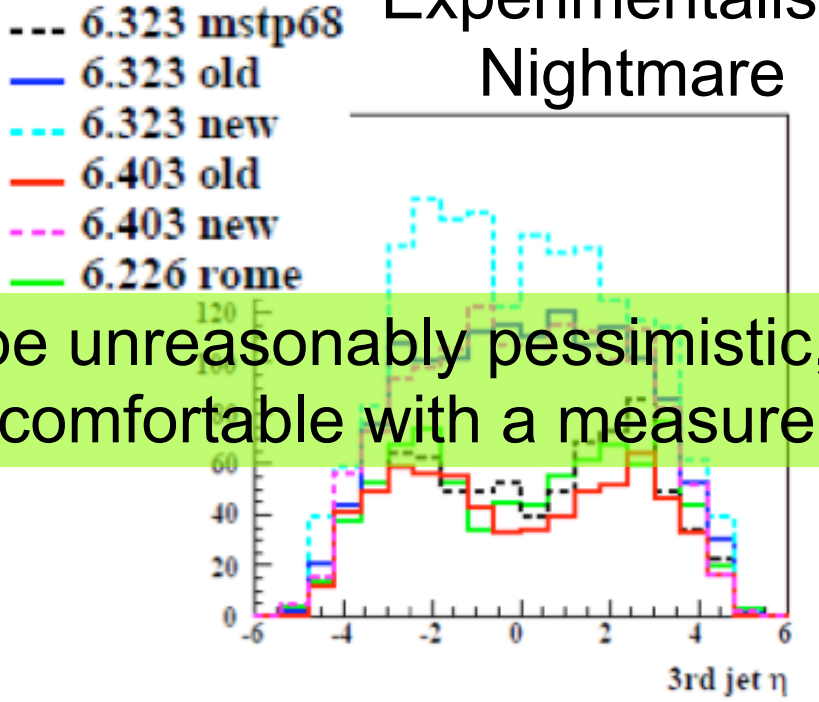


Experimentalist's Nightmare



The nightmare illustration may be unreasonably pessimistic, but experimentalists would be more comfortable with a measurement

Motivation & Goals

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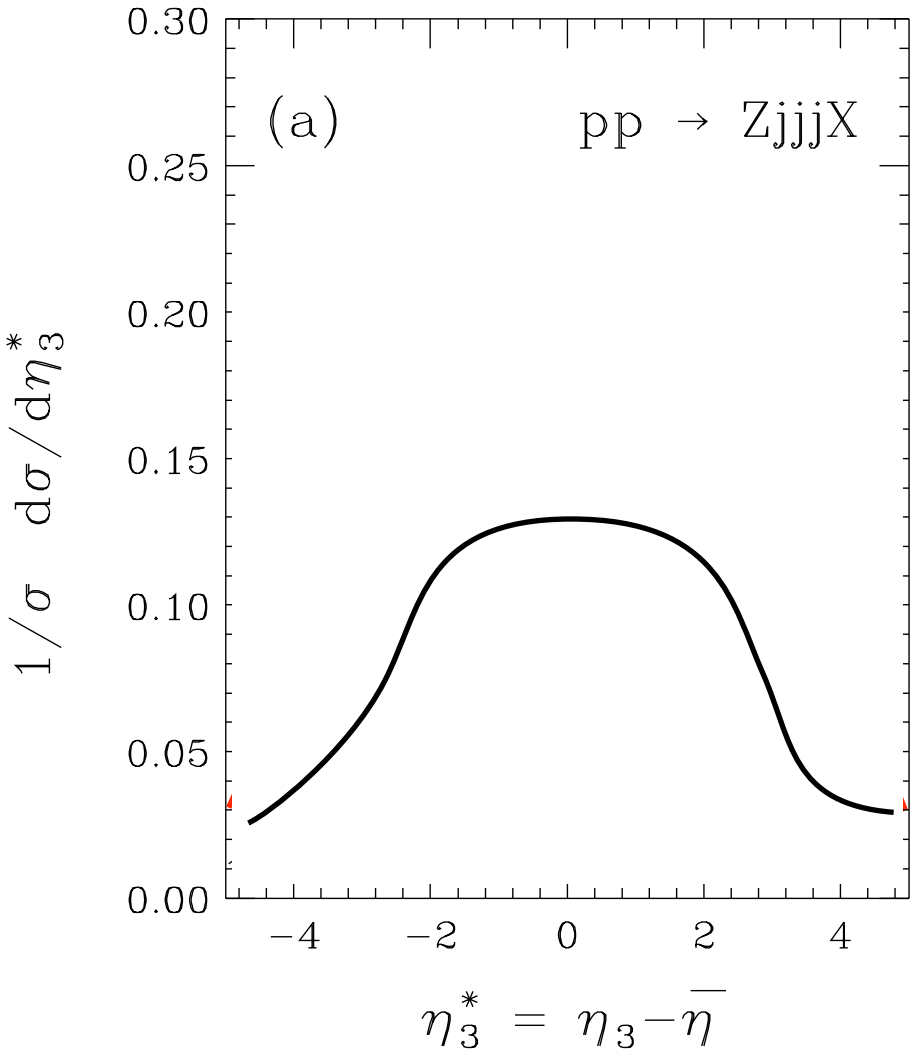
In the Z+jjj sample, we observe the sum of EW & QCD

- what are the contributions from EW & QCD?



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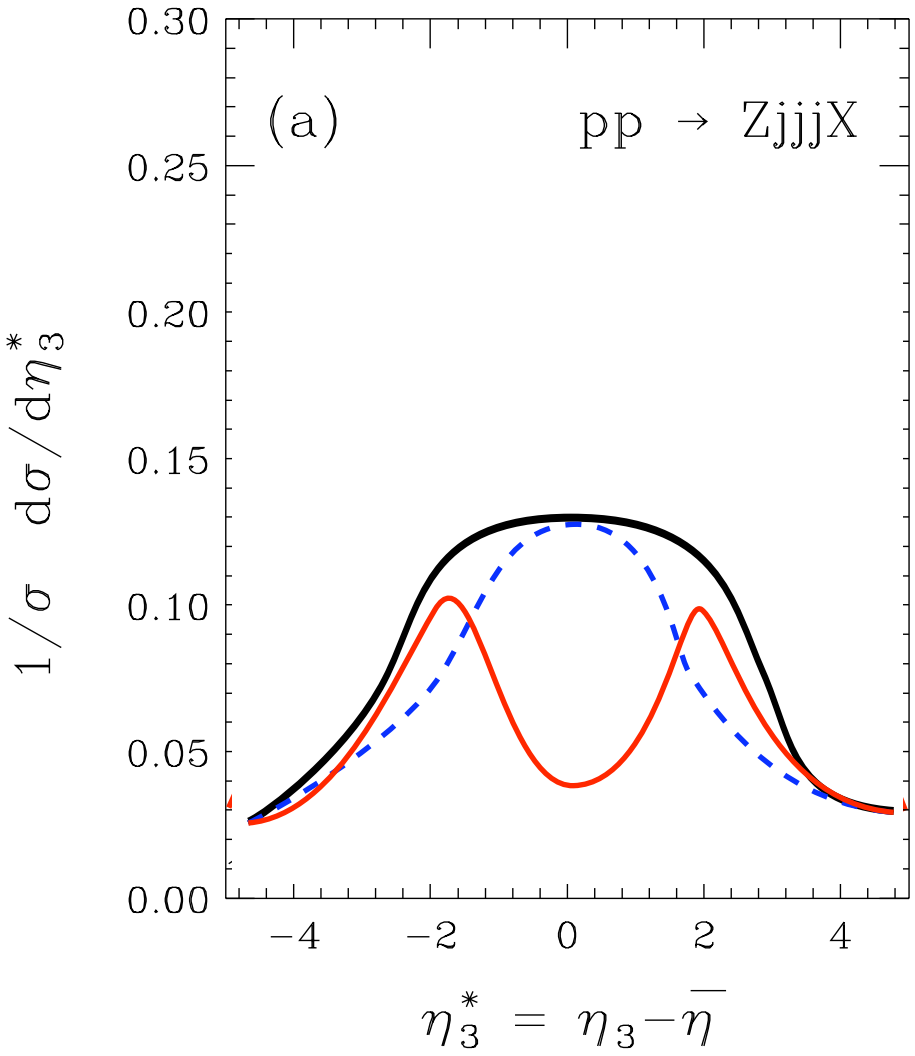

Motivation & Goals

BROOKHAVEN NATIONAL LABORATORY

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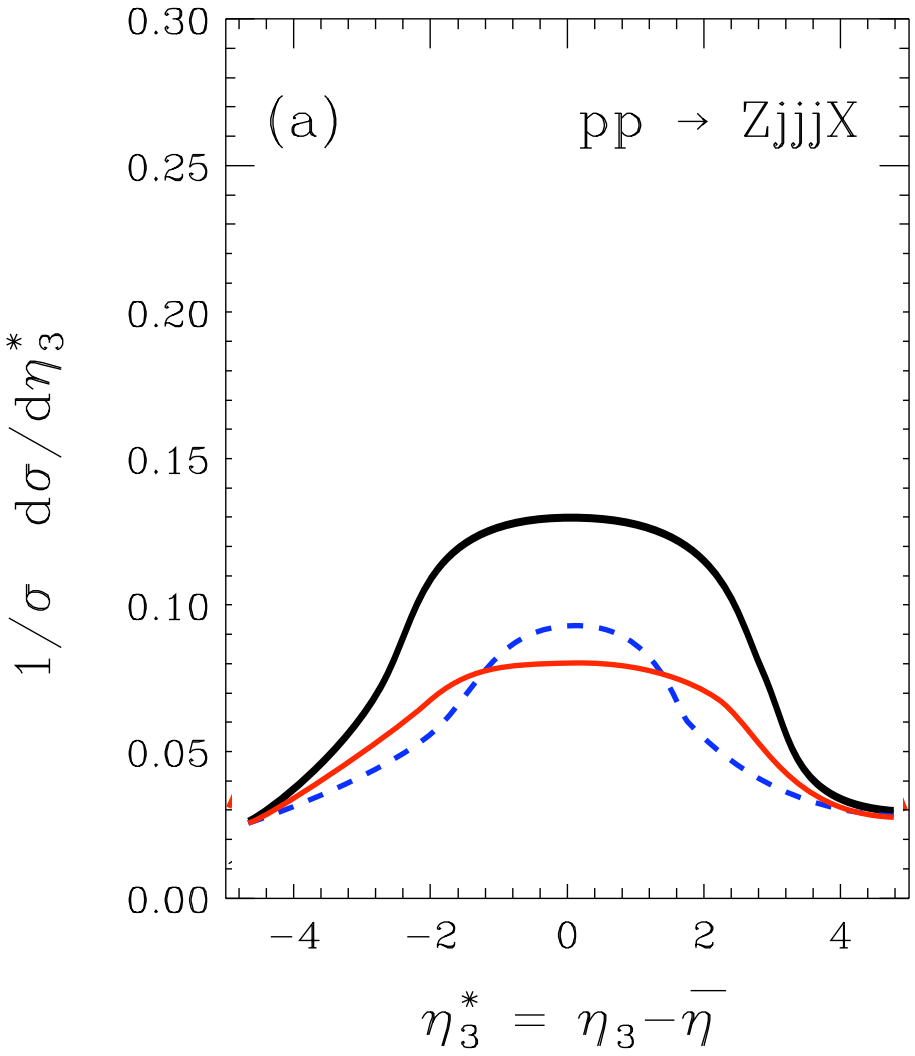


Motivation & Goals

BROOKHAVEN NATIONAL LABORATORY

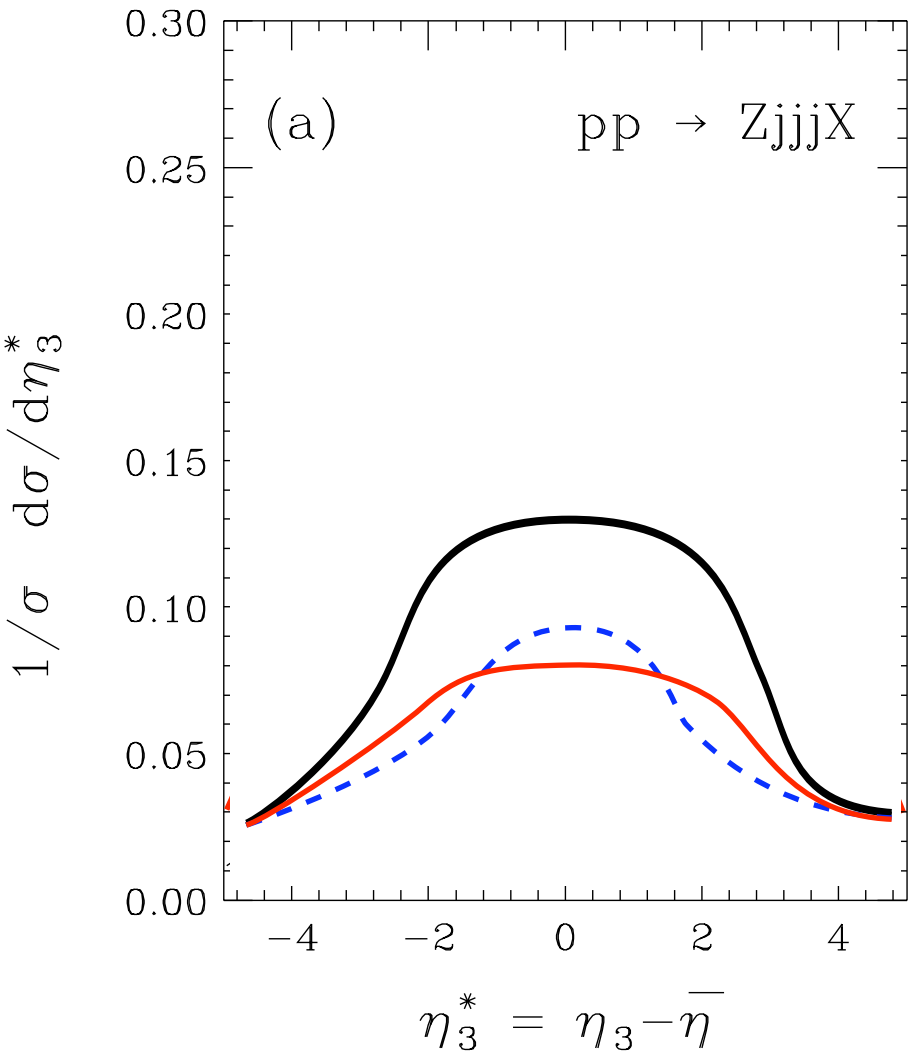
In the Z+jjj sample, we observe the sum of EW & QCD

- what are the contributions from EW & QCD?

If we can unfold the EW & QCD components:

1) check predictions for EW Z+jets
   - if problems, learn what effects are missing
   - ultimately, improve our prediction for Higgs.
2) isolate VBF diagrams in Z production and extrapolate to Higgs production

Our Goal: minimize the error on CJV efficiency for signal



Unfolding EW & QCD Z+jets

Idea for Measuring CJV with Data

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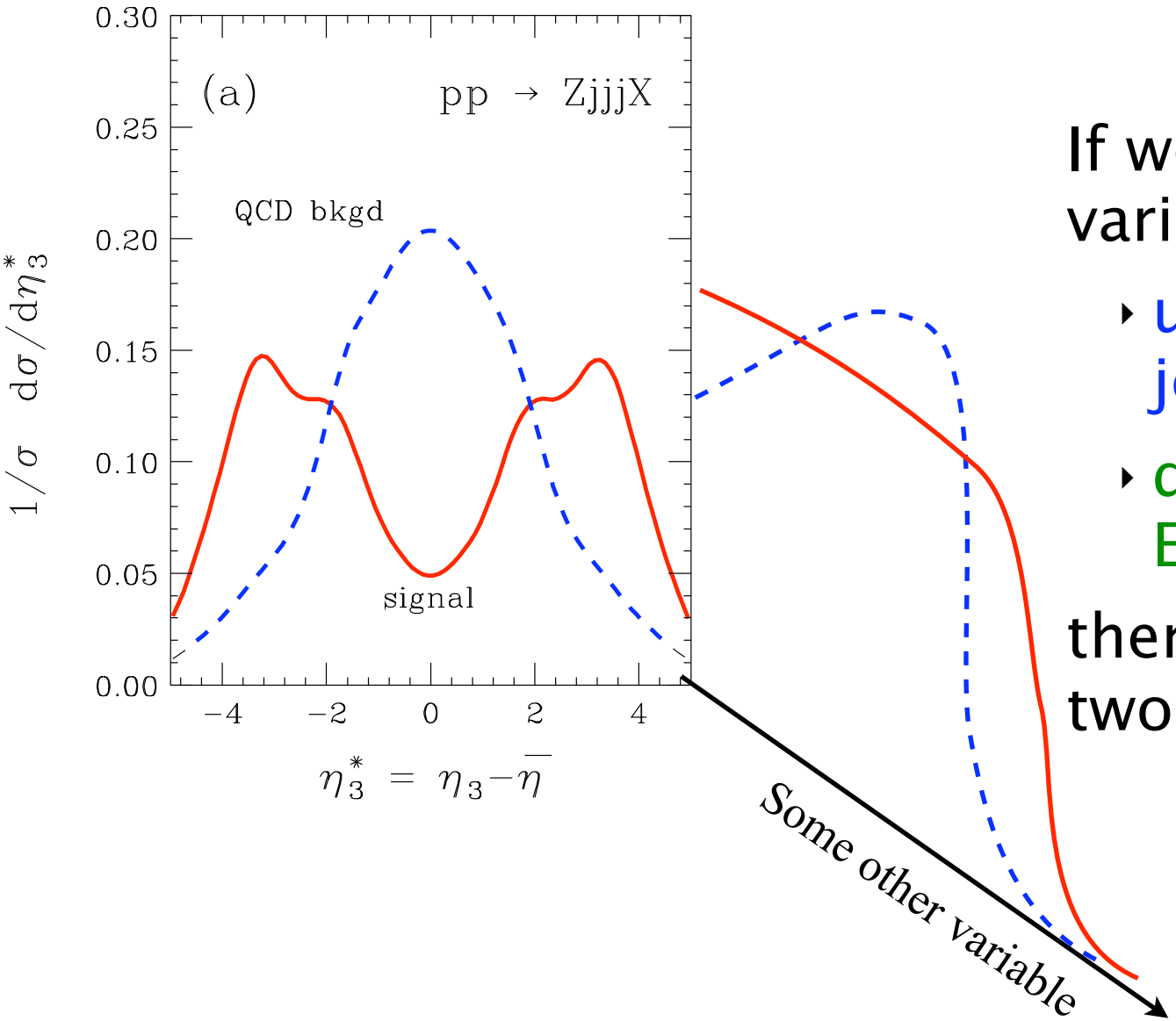
By looking at $Z \to e^+e^-$ & $Z \to \mu^+\mu^-$ we remove Higgs contribution



If we can find some other variable that is:

- uncorrelated to the 3rd jet's distribution
- discriminates between EW & QCD

then we can unfold the two contributions

Idea for Measuring CJV with Data

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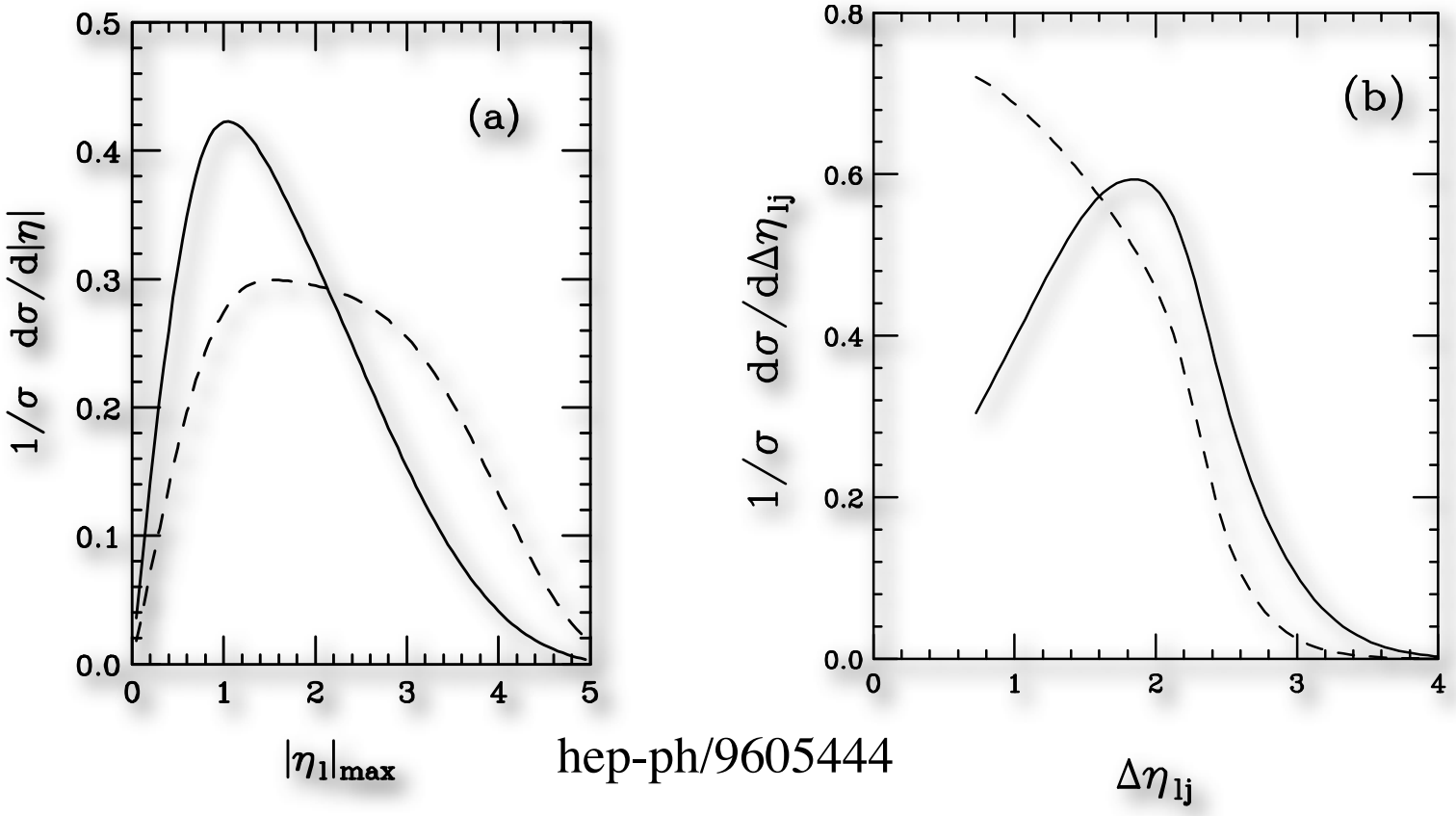
My original idea was to look at rapidity of Z.

- Showed discrimination. Don't expect correlation. Can't find plots.
- Looking in literature, other candidates are:

Probing color-singlet exchange in $Z + 2$-jet events at the LHC

D. Rainwater[1], R. Szalapski[2], and D. Zeppenfeld[1]



hep-ph/9605444

good discrimination, but correlated to jets

Back-of-the-envelope Rate Estimates

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From ATLAS low-mass Higgs note $Z \to \tau\tau \to ll$

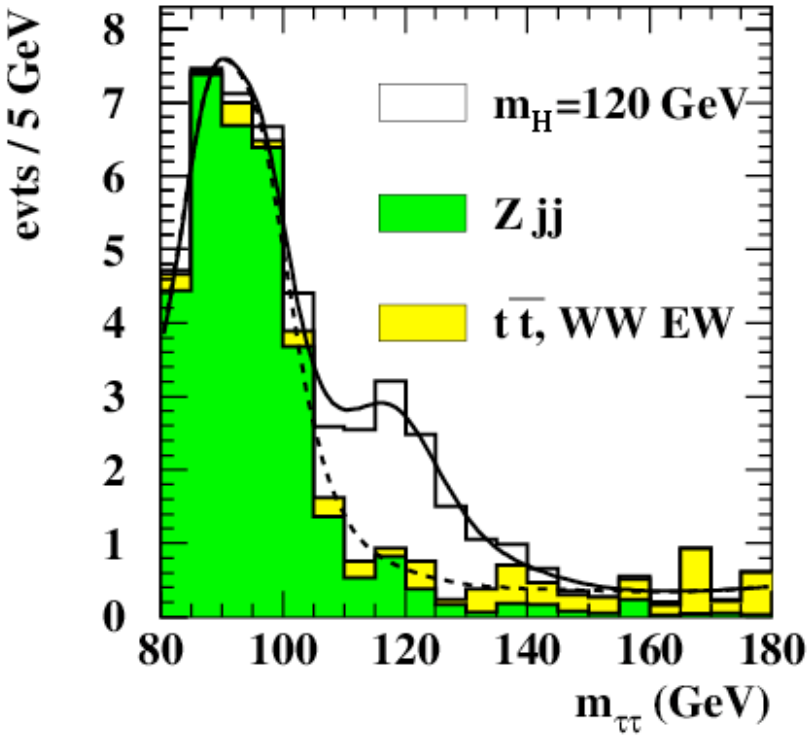
- EW 1.17 fb, QCD 9.38 fb
- Gain about x8 from $BR(\tau\tau \to ll)$, and x2 for $ee/\mu\mu$
- small gains from harder p_T leptons, no ETmiss cut

Expect roughly 18 fb for EW and 150 fb for QCD with 2 jets

- fraction with a 30 GeV 3rd jet will be ~20% & 80%, respectively

	signal (fb)		background (fb)					
	VV	gg	$t\bar{t}+jets$	$WW+jets$ EW	$WW+jets$ QCD	$\gamma^*/Z+jets$ EW	$\gamma^*/Z+jets$ QCD	Total
Lepton acceptance	5.55		2014.	18.2	669.8	11.6	2150.	4864.
+ Forward Tagging	1.31		42.0	9.50	0.38	2.20	27.5	81.6
+ P_T^{miss}	0.85		29.2	7.38	0.21	1.21	12.4	50.4
+ Jet mass	0.76		20.9	7.36	0.11	1.17	9.38	38.9
+ Jet veto	0.55		2.70	5.74	0.05	1.11	4.56	14.2
+ Angular cuts	0.40		0.74	1.20	0.04	0.57	3.39	5.94
+ Tau reconstruction	0.37		0.12	0.28	0.001	0.49	2.84	3.73
+ Mass window	0.27	0.01	0.03	0.02	0.0	0.04	0.15	0.24
$H \to \tau\tau \to e\mu$	0.27	0.01	0.03	0.02	0.0	0.04	0.15	0.24
$H \to \tau\tau \to ee$	0.13	0.01	0.01	0.01	0.0	0.02	0.07	0.11
$H \to \tau\tau \to \mu\mu$	0.14	0.01	0.01	0.01	0.0	0.02	0.07	0.11

Eur.Phys.J.C32S2:19-54,2004.



This Weekend's MadGraph Run

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Generate $pp \to e^+e^-jjj$ with:

- EW order = 99; QCD order = 1 for EW Z+jets
  - 19632 diagrams!
- EW order = 2; QCD order = 99 for QCD Z+jets
  - 6504 diagrams

Cuts: (Looser than ATLAS note, no explicit M_{jj} cut)

- $p_T^{jet} > 30$ GeV (all jets, including 3rd jet)
- $\Delta\eta_{jj} > 4$ (requires modification to cuts.f)
- $M_{e^+e^-} > 80$ GeV
- $\Delta R_{jj} > 0.7$

Preliminary cross-sections

- QCD: 950 fb (10x higher than "envelope". Probably, Missing M_{jj} cut)
- EW: >7.6 fb ? (Generation still running.)

Used Local PCs. Very nice resource!

Relevant Distributions

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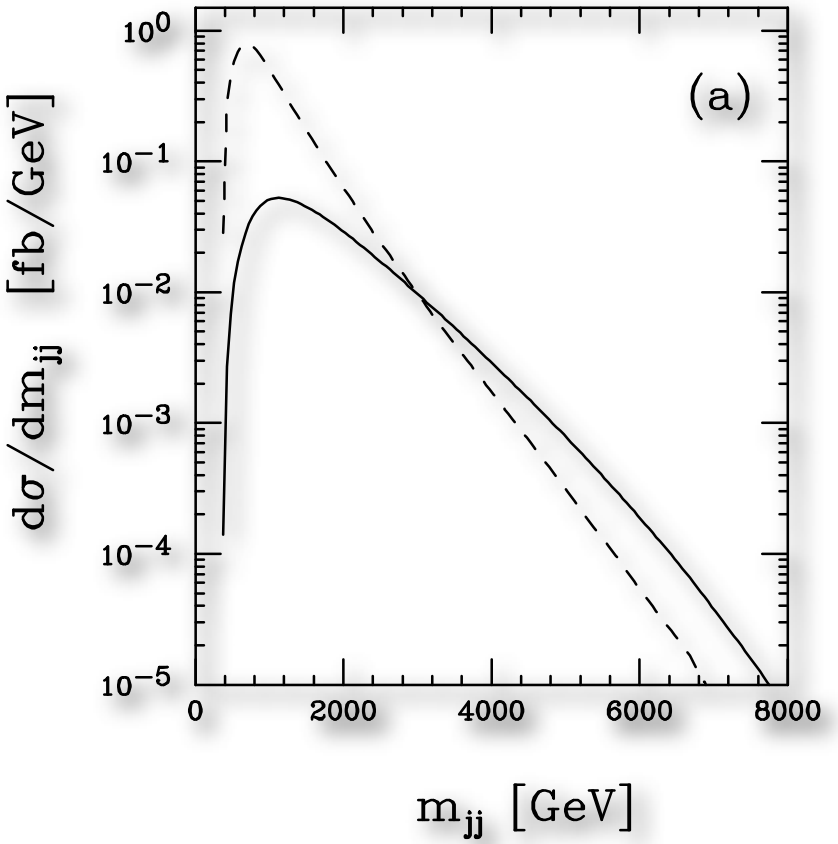
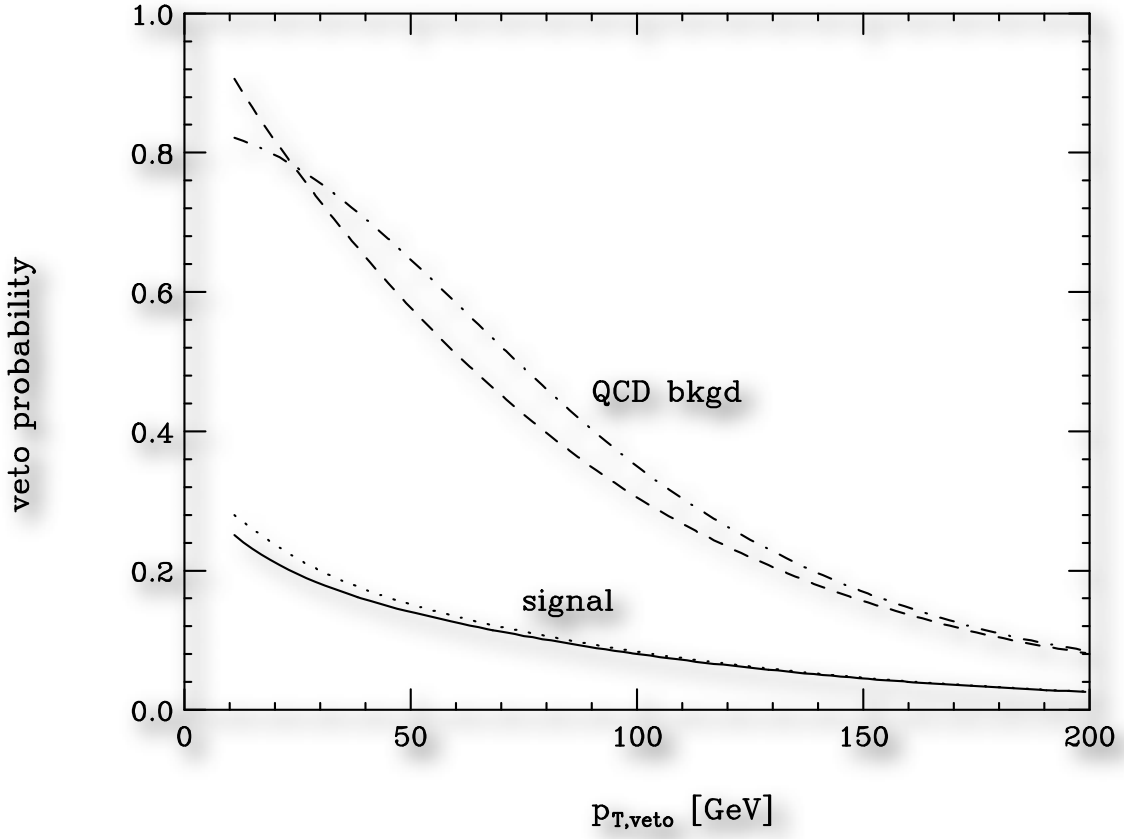
Lack of M_{jj} cut will enhance QCD.

- Will add this cut later, but requires modification to cuts.f in MadGraph.

Previous results for Central Jet Veto mean Zjjj production will have lower x-section than "back of the envelope"





sPlot Extension

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BaBar has developed a technique called sPlot, which provides a nice formalism for unfolding distributions in this way

- in the case of only one discriminating variable, it is trivial
- in the case of multiple discriminating variables, correlations become important

$$ {}_s\mathcal{P}_{\mathrm{n}}(y_e) = \frac{\sum_{j=1}^{\mathrm{Ns}} \mathbf{V}_{\mathrm{n}j} \mathrm{f}_j(y_e)}{\sum_{k=1}^{\mathrm{Ns}} N_k \mathrm{f}_k(y_e)} $$

${}_s\mathcal{P}lot$: Nucl.Instrum.Meth.A555 [physics/0402083]

a statistical tool to unfold data distributions

M. Pivk[a] and F.R. Le Diberder[b]

Unfolding Results

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Just generated the events, no results on the unfolding yet.

Plan to have results for Les Houches contribution

Isolating the VBF Part of EW Z+jets

Contribution VBF Signal Graphs

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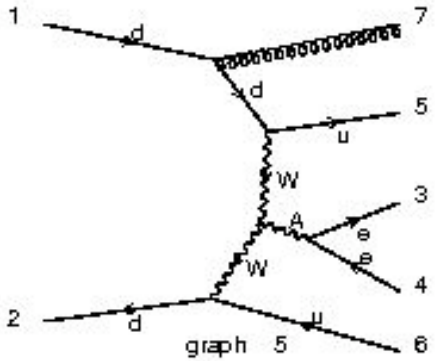
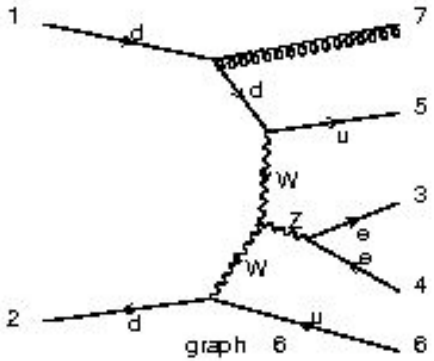
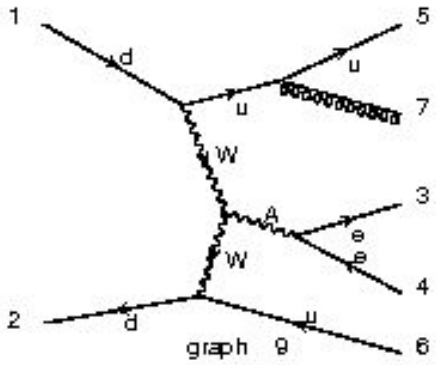
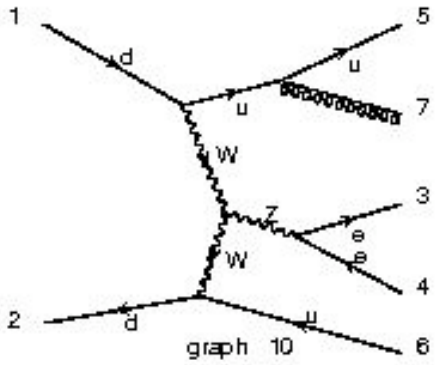
These graphs are very similar to the VBF Higgs signal, but other EW Z+jets diagrams are also contributing

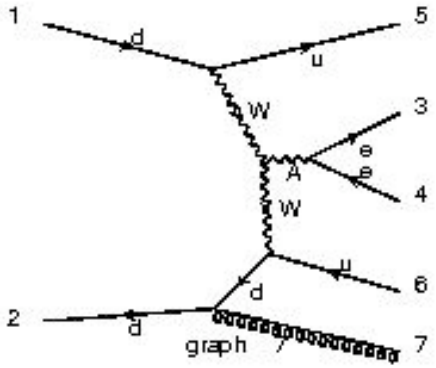
- No clear way to talk about contribution from a particular graph
- MadEvent integrates efficiently for each graph, can talk about contribution of total x-sec. from a given P.S. mapping

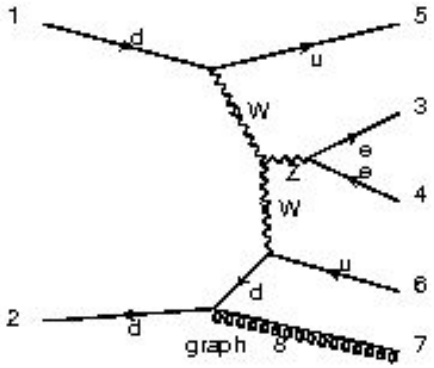


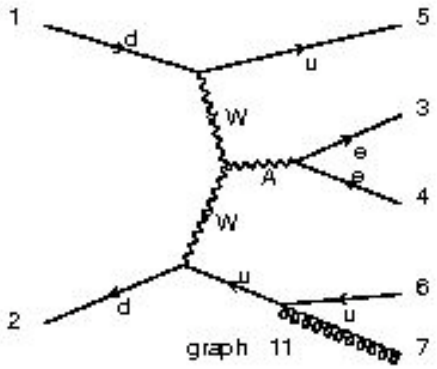


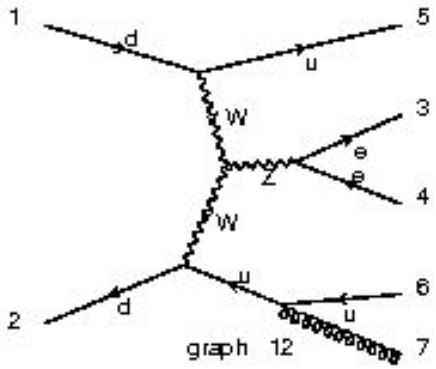












Non-VBF EW Zjjj Diagrams

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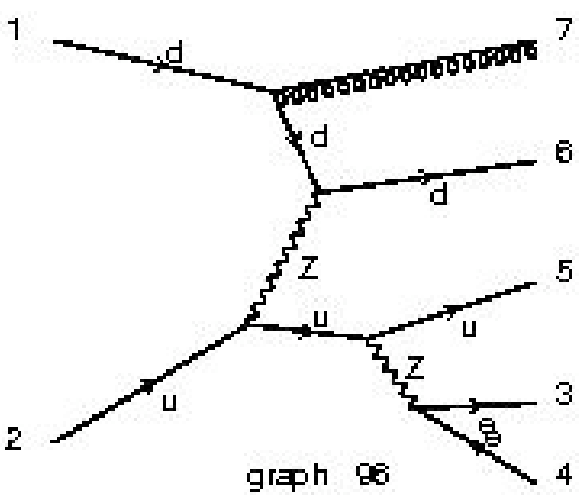
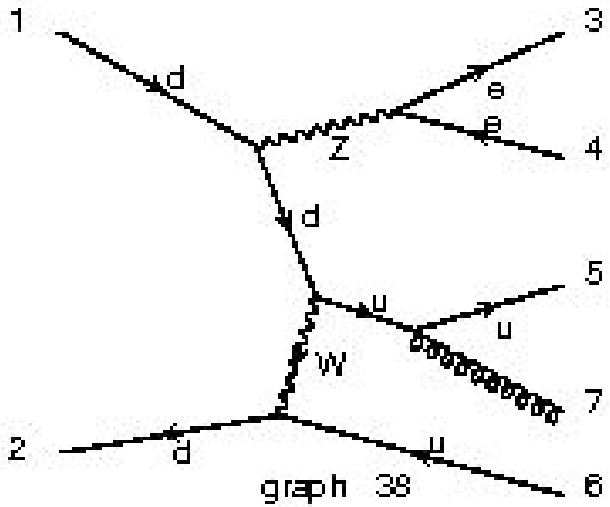
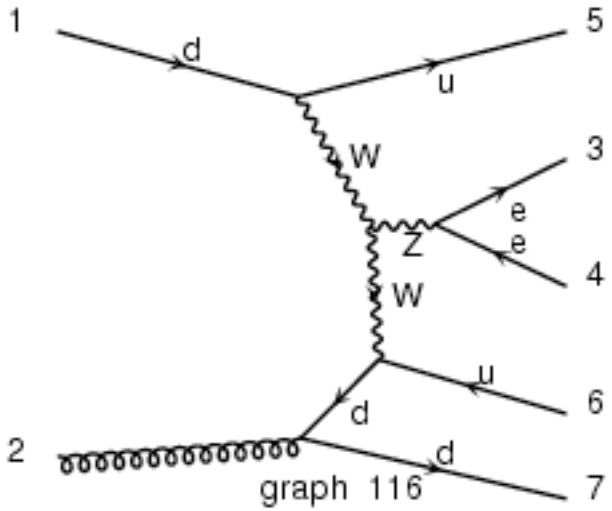
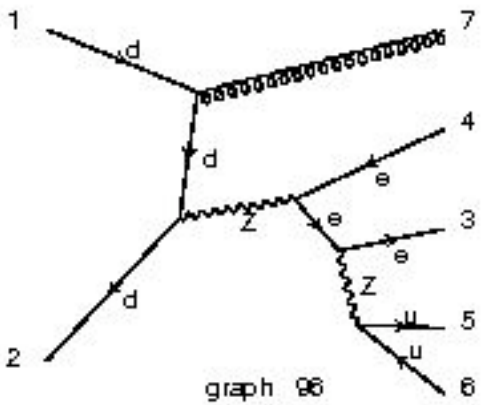
Major non-VBF contribution from diagrams like this

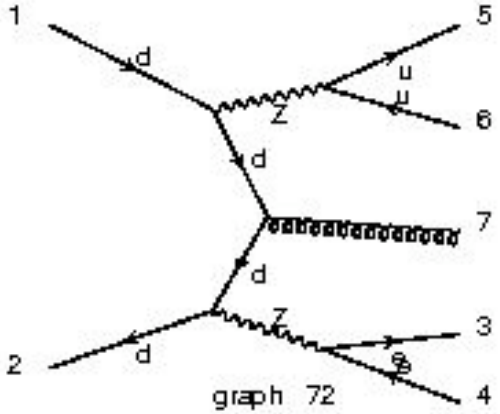


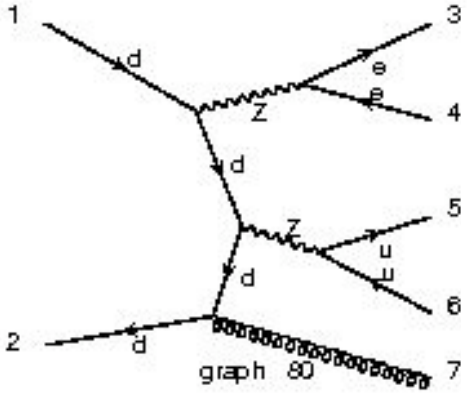


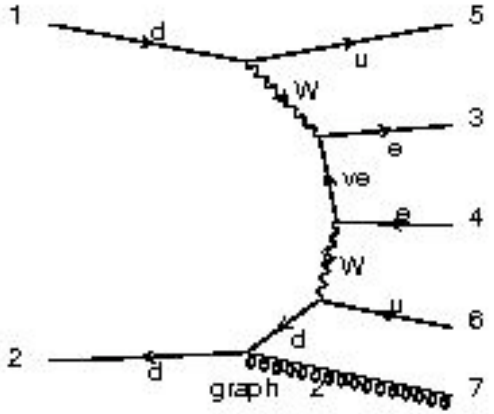


Some less important non-VBF diagrams:









Processes with no VBF-like component

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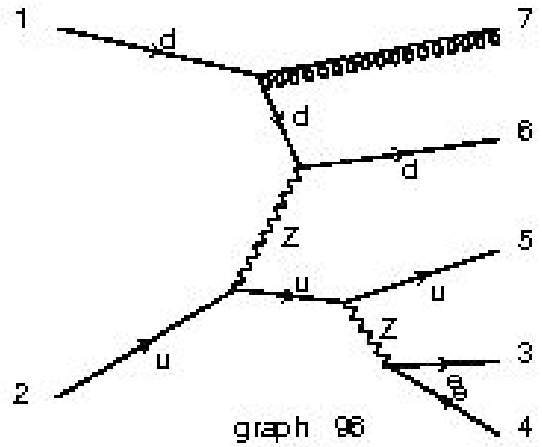
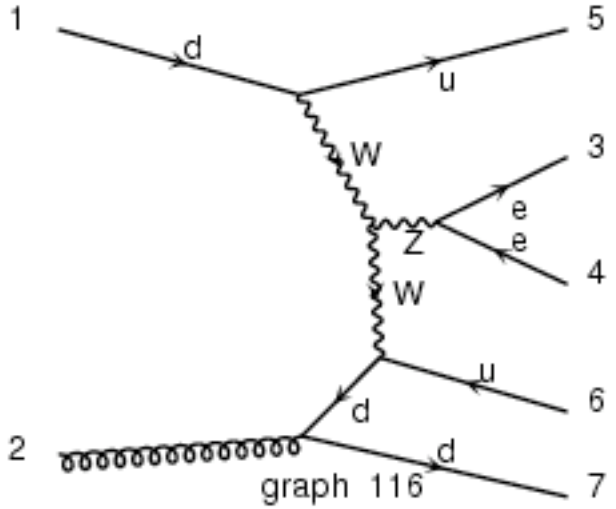
This process has no VBF-like diagrams and a 50% of cross-section

P0du_e-e+udg	3,910 ab



Gluon-initiated processes have VBF component, but color-flow between jets is different.

P0dg_e-e+uuxd	284 ab
P0dg_e-e+uscx	247 ab



Contribution From VBF Diagrams

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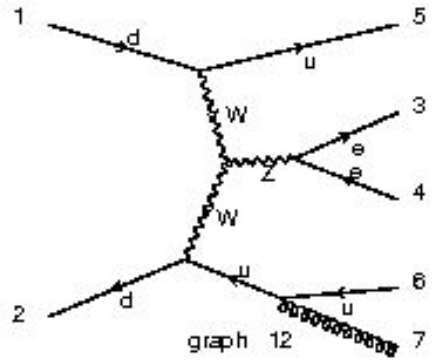
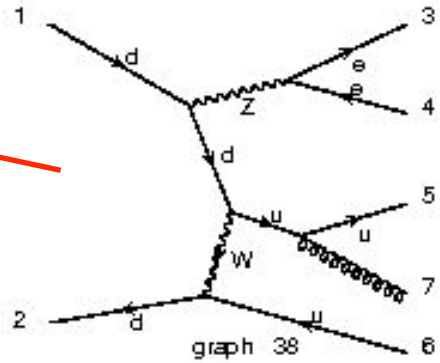
ddx_e-e+uuxg

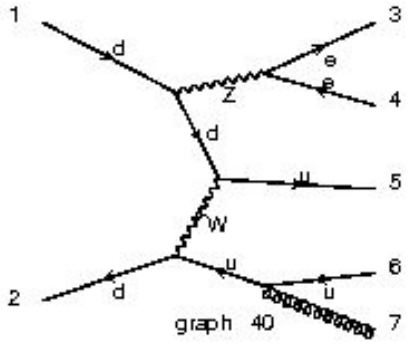
s= 450.825± 100.591(ab)

Graph	Cross Sect(ab)	Error(ab)	Events (K)	Eff	Unwgt	Luminosity
Sum	**450.825**	**100.591**	**1278**	**252.3**		
G12	72.116	14.083	7	17.4	11	0.15
G10	68.908	6.154	6	7.3	14	0.20
G6	49.542	3.568	14	8.7	17	0.34
G8	41.869	3.639	9	8.4	13	0.31
G38	21.722	2.562	3	7.2	7	0.32
G40	18.414	2.415	4	9.2	11	0.60
G28	16.596	11.649	0	15.3	7	0.42
G20	16.281	1.770	7	9.5	10	0.61
G34	13.456	1.229	8	8.4	14	1.04
G30	13.363	3.500	0	6.1	3	0.23
G18	11.929	1.823	6	12.2	8	0.67
G36	11.632	6.272	1	21.5	4	0.34
G50	11.608	2.067	6	14.3	7	0.60
G48	11.194	2.649	7	20.5	14	1.25
G24	10.664	18.616	1	59.7	2	0.19
G26	9.679	3.401	10	36.0	3	0.31
G44	9.035	0.763	13	9.9	17	1.88

0.232 fb from VBF diagrams about 50% of x-section for this process







Contribution from VBF Diagrams

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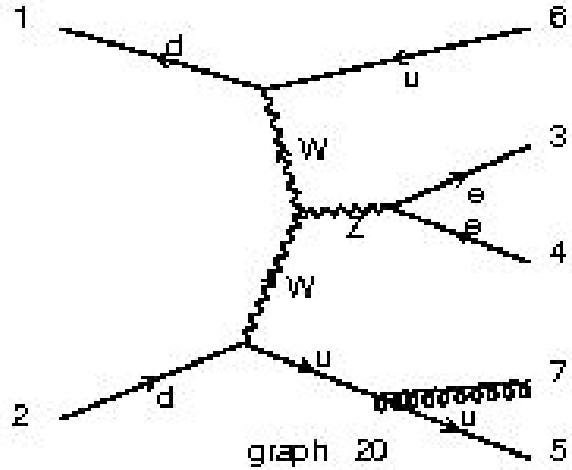
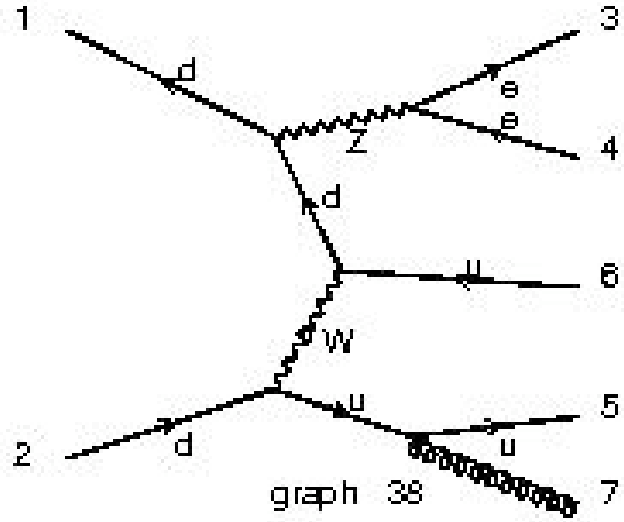
dxd_e-e+uuxg

s= 480.644± 85.226(ab)

Graph	Cross Sect(ab)	Error(ab)
Sum	480.644	85.226
G20	74.420	7.803
G22	71.971	10.409
G18	51.605	6.955
G16	46.029	3.386
G38	25.821	3.740
G40	21.267	3.247
G8	18.629	3.946
G10	18.433	11.424
G28	13.845	1.708

0.244 fb from VBF diagrams
about 50% of x-section for this process





Homework for the theorists

How different is the radiation of the third jet for these processes in the signal-like region?

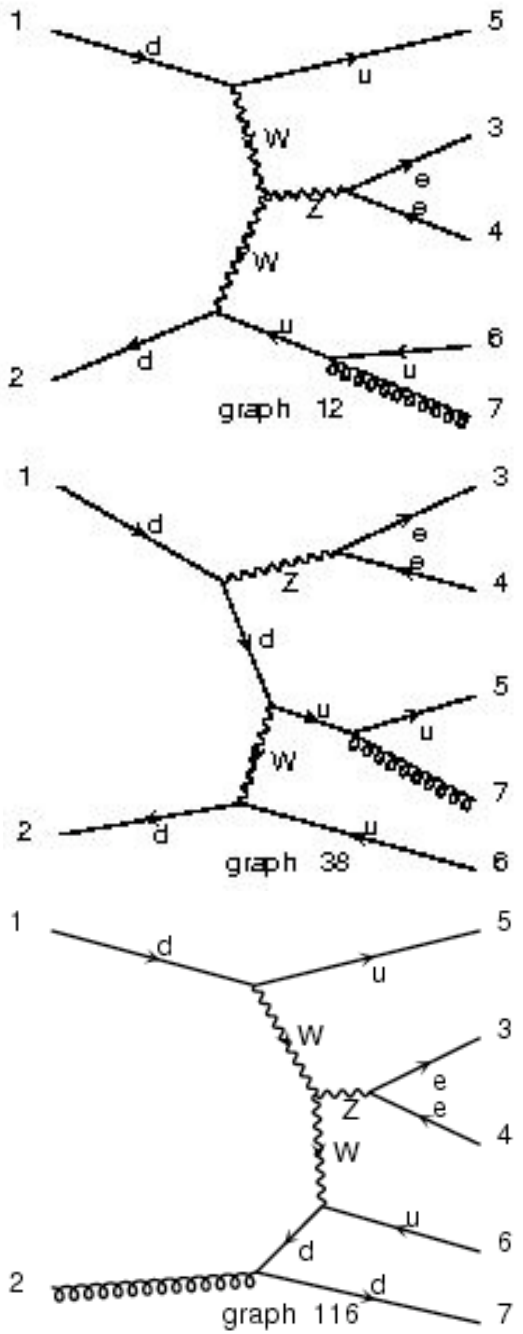
- in both cases there is no color flow between the quark lines

How different is the radiation of a third jet in the sum of these processes from the Higgs?

- we need to quantify it in terms of uncertainty in the CJV efficiency / survival probability

If it is significantly different and we really need to isolate the VBF diagram:

- what is theoretical uncertainty on VBF contribution
- are there any ideas for what observable can isolate the VBF diagram?



Future Plans & Other Worries

Impact of P_T cut on 3rd Jet

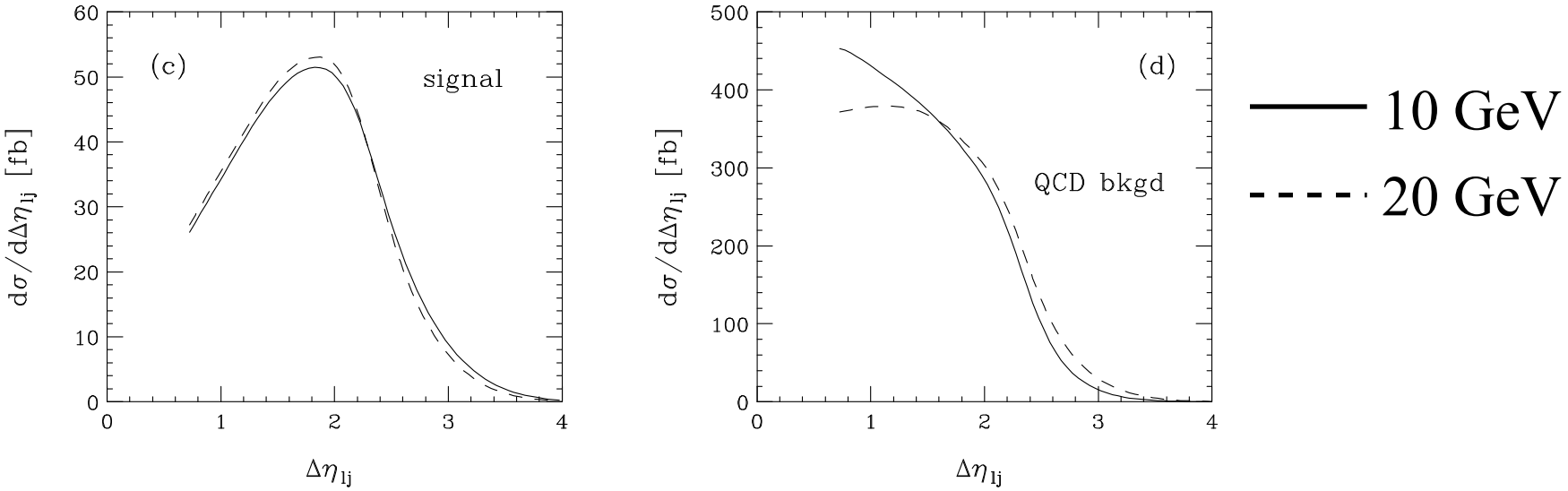


FIG. 7. Same as Fig. 6 but for the dependence of the minijet activity on the minimal separation $\Delta\eta_{\ell j}$ of the Z-decay leptons from the two tagging jets. See text for details.

Rainwater and Zeppenfeld already looked at how these discriminating variables change with the 3rd jet p_T

QCD Uncertainties

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Ideally, the discriminating variable(s) we would use for unfolding will not be sensitive to QCD uncertainties that also affect the 3rd jet's distribution.

- PDF uncertainties on rapidity of Z
- NLO corrections to $\eta_{l\,max}$ & $\Delta\eta_{l\,j}$
- others (input from audience)

Will try unfolding with Sherpa Z+nJets samples with full simulation, but will be private ATLAS results for some time.

Open to other suggestions.

Central Cluster Veto

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The Central Jet Veto is important, but at low pT:

- efficiency of jet algorithms is poor
  - so CJV is not as effective as one would hope
- purity of jet algorithms is poor
  - fake jets from underlying event, pile-up, and purely experimental effects

Idea: Don't use jet algorithms, just veto on excess of hadronic energy between the tagging jets

- Gunther Dissertori suggested "Jet Area" technique by Cacciari & Salam to deal with pile-up and underlying event
  - larger veto region reduces s/b, but reduces relative fluctuations in b

Conclusions

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Understanding the Central Jet Veto efficiency is crucial for coupling measurements, limits, and optimization of analysis

- current tools that include parton shower have large uncertainties, want to measure from data

By identifying an uncorrelated variable that discriminates between EW and QCD, we can unfold the distributions

- several candidate variables identified, need to test
- provide test for existing predictions

Initial results indicate that in signal like region ~20% of EW process comes from VBF diagrams

- is that good enough? what is the uncertainty in extrapolating to the Higgs?

Many thanks for the very productive workshop!